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May 7, 1998

EXPRESS MAIL

File 8998

Commissioner of Patents
and Trademarks
Washington, D.C. 20231

Re: Applicant: Barry G. Broome et al
Patent Application entitled
SINGLE OBJECTIVE LENS FOR USE
WITH CD OR DVD OPTICAL DISKS

Sir:

Pursuant to 37 C.F.R. § 1.10, the undersigned hereby certifies that the following is being deposited as "Express Mail" with the United States Postal Service on Thursday, May 7, 1998, and requests that the above-entitled application be accorded a filing date of May 7, 1998. The "Express Mail" mailing number is EE 407 392 996 US. The items transmitted herewith include:

1. Patent specification with 12 claims;

2. Declaration and two small entity papers;

3. Twelve sheets of informal drawings, and

4. Small entity filing fee in the amount of $436.

If there any additional fees, please charge our deposit account No. 05-0420.

The assignment and recording fee will be forwarded at a later date.

Very truly yours,

Bruce H. Johnsonbaugh

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encs.
8998.004

Deposited as "Express Mail" on May 7, 1998
under Express Mail mailing label #EE407392996US.

Dated: 5/7/98 Bruce H. Johnsonbaugh
Bruce H. Johnsonbaugh
Reg. No. 24,982

SINGLE OBJECTIVE LENS FOR USE WITH CD OR DVD OPTICAL DISKS

Background and Brief Summary of the Invention

The present invention relates to a single objective lens that can be used with either CD optical disks or DVD optical disks.

Several different formats of optical disk are known in the prior art. The two most commonly used formats are the CD and the DVD. These two optical disk formats store different data densities; the DVD uses a much smaller track and much smaller "pits" to record a higher data density. The CD (Compact Disk) appears in wide use as both a CD-DA (Company Disk-Digital Audio) and a CD-ROM (Compact Disk-Read Only Memory); the format is identical for these two species. The DVD (Digital Versatile Disk) appears in use as a digital video (movie) storage or an extended computer memory product.

Data records on both CD and DVD formats are in "pits" formed in a reflective surface of the disk. These "pits" are actually in the form of short "trenches" that lie along a track that spirals around the disk surface. The CD "pit" is typically 0.50 micrometer (uM) wide and between 0.83 to 3.05 uM long. The track pitch is 1.6 uM and the depth of the "pit" is 0.20 uM. To achieve higher data density, the DVD "pit" is typically 0.3 uM wide and between 0.40 to 1.5 uM long. The track pitch is 0.74 uM and the "pit" depth is 0.16 uM. The CD can reliably record about 650MB of digital data whereas the DVD can reliably record about

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4.7GB of digital data on one side of the disk (both sides can be used on a DVD).

The width and depth of the CD "pit" was determined by early optical fabrication technology which limited the objective lens to 0.45 NA (Numerical Aperture), and by early laser diode technology (a 780 nm emission line). Because cost-effective objective lenses could be made no faster than 0.45 NA (i.e. a relative aperture of f/1.11) and lower wavelength laser diode emission lines were not available, the size of a diffraction-limited laser spot image was limited to 1.0 uM at the Full-Width-Half-Maximum intensity points (FWHM). The CD "pit" depth is chosen to be one-fourth of the laser wavelength (0.20 uM) and the "pit" width is chosen to be about half the laser spot diameter (0.50 uM). This arrangement permits about half of the wavefront in the laser spot to reflect from the bottom of the "pit" and about half of the wavefront to reflect from the surface surrounding the "pit." The two reflected components are half a wavelength out of phase so they interfere destructively. No signal is returned to the objective lens when a "pit" is present. When no "pit" is present, the full wavefront reflects from the surrounding surface and light is returned to the objective lens. This is the digital encoding process for most optical disks. There are other subtle effects that this encoding process introduces such as diffraction at the edges of the pit, but the interference process is thought to be the principal phenomenon.

The newer DVD format has been enabled by two technology developments; a 650 nm laser diode has become commercially viable and 0.60 NA objective lenses have become cost-effective. The combination of these two factors produces a diffraction-limited laser spot with 0.64 uM FWHM, so the DVD "pit" width becomes 0.32 uM and the "pit" depth becomes 0.16 uM.

Several optical disk products have been produced in the prior art that combine CD and DVD formats in the same optical reader. In order to achieve this goal, the prior art uses two laser diodes plus two lenses and moves either one set (laser diode plus objective for CD format) or the other set (laser diode plus objective for DVD format) over the disk that is to be read. No prior art single objective design is known that can operate with either the CD or DVD formats.

The invention of this application is a single lens that can operate with either the CD format (with 780 nm laser diode) or with the DVD format (with 650 nm laser diode). No moving parts are required with this invention because the appropriate laser diode can be turned on electrically and introduced to the objective lens via a dichroic beamsplitter or a grating structure.

Brief Description of the Drawings

Fig. 1 is a schematic representation of a typical prior art CD objective lens;

Fig. 2 shows the wavefront error of the prior art objective lens shown in Fig. 1;

Fig. 3 is a graphical representation of the depth of focus defined as the RMS wavefront error of the prior art lens of Fig. 1;

Fig. 4 shows a single objective lens according to the present invention and related system components operating with either a CD format (.45 NA ray fan and thick disk substrate) or a DVD format (.60 NA ray fan and thin disk substrate);

Fig. 5 shows a schematic representation of one embodiment of the single objective lens according to the present invention using aspheric surfaces;

Fig. 6 is a graphical representation of the wavefront errors of the single objective lens shown in Fig. 5;

Fig. 7 is a graphical representation showing the depth of focus defined as the RMS wavefront error for the single objective lens shown in Fig. 5;

Fig. 8 is a schematic representation of a second and preferred embodiment of the present invention using one diffractive and one aspheric surface;

Fig. 9 is a graphical representation showing the wavefront errors for the lens design shown in Fig. 8;

Fig. 10 is a graphical representation showing the depth of focus properties of the system shown in Fig. 8;

Fig. 11 is a graphical representation of the percentage of light focused by a diffractive surface showing wavelength dependency; and

Fig. 12 is an exaggerated representation of the diffractive surface used in the preferred embodiment shown in Fig. 8.

Detailed Description of the Drawings

Fig. 1 shows a typical prior art CD objective operating at 0.45 NA and with a 780 nm laser diode source. This objective uses injection molded PMMA plastic plus aspheric surfaces on both sides of the lens. The objective forms a diffraction-limited image on the rear surface of a 1.2 mm thick polycarbonate plastic cover on the CD.

Fig. 2 shows the wavefront error of the prior art system of Fig. 1 (the horizontal axis is the dimension across the lens aperture and the vertical axis is the wavefront error). The Marechal condition for a diffraction-limited optical system is 0.070 RMS waves. This prior art lens has a 0.035 RMS wavefront error and is diffraction-limited by this criterion. This RMS wavefront error is equivalent to a 0.140 P-V wavefront error and the Rayleigh criterion for a diffraction-limited lens is a wavefront error of less than 0.250 PV waves, so the lens is diffraction-limited by this criterion as well.

Fig. 3 shows the RMS wavefront error of the prior art system of Fig. 1 as a function of the depth of focus. Because the objective must be rapidly auto-focused during reading operations, there must be a useful depth of focus where the objective performance is essentially diffraction-limited. This prior art nominal design is essentially diffraction-limited over a +/-1.5 micrometer range. When the objective is manufactured,

fabrication tolerances reduce performance and the useful depth of focus is reduced to about +/-1.0 micrometer. The essentially diffraction-limited depth of focus requirement forces very stringent fabrication tolerances on this class of objective lens.

Fig. 4 shows the first embodiment of the objective lens design of the present invention that could operate with both CD and DVD formats. Lens 20 has a large aperture that permits ray fans for either a 0.45 NA (and 780 nm laser diode) operation or a 0.60 NA (and 650 nm laser diode) operation. This figure shows that the central zone of the lens must be used to control the 0.45 NA and 780 nm laser diode operation and that the outer zone can be independently designed for the 0.60 NA and 650 nm laser diode operation. However, the central zone will also contribute to the 0.60 NA and 650 nm laser diode operation and this is the reason that prior art objectives designers have not been able to use a single element objective for both CD and DVD reader systems. As shown in Fig. 4, disk 30 may either be a DVD format disk or a CD format disk. Disk support and drive means shown generally as 40 includes a conventional drive plate 41, spindle 42 and drive motor 43 as known in the art. First and second laser diodes 51 and 52, respectively, operate with output beams of approximately 780 nm and 650 nm, respectively. The laser diode output beams pass through beam-splitters 71 and 72 and are directed towards collimating lens 60. Light 61 exiting the collimating lens 60 passes through single element objective lens 20, is reflected from the CD or DVD disk, and is deflected by

beam-splitter 72 onto photodetector 80, where changes in output power are utilized to read the disk, as is known in the art. It is significant that the single element objective lens 20 of the present invention is positioned between the beam-splitter 70 and disk 30 in a pathway of collimated light. Several of the prior art systems position the objective lens in a pathway of non-collimated light requiring that the placement of the objective lens be very precise. The placement of components shown in Fig. 4 can be varied without departing from the invention and alternate beam-splitters and collimators may be used. Although the embodiments shown and discussed herein disclose lasers 51 and 52 operating at 780 nm and 650 mn, it is to be understood that the invention can be applied to the general case wherein lasers can be operated with different output wavelengths including shorter wavelength lasers as they become commercially available. Another significant aspect of the single element objective lens 20 as used in the present invention is that the lens is a single optical element in contrast to the typical two element prior art design which utilizes either an objective lens and hologram or an objective lens and a second lens element. Full alignment of both elements in the prior art requires alignment of five degrees of freedom of the two combined elements (centration of both elements and two degrees of tilt for each element), whereas the use of the single element, fixed objective lens 20 of the present invention greatly simplifies alignment of the lens.

The first embodiment of the present invention is shown in greater detail in Fig. 5. This is a molded COC (Cyclic Olefin Copolymer) plastic lens 20 with aspheric first surface 21 and aspheric second surface 22. This invention uses the fact that the polycarbonate disk cover plate 30 varies from 0.6 mm in the DVD format 31 to 1.2 mm in the CD format 32 and that the spherical aberration introduced by the plate is twice as large for the CD format. Concurrently, the objective DVD format NA is 0.60 and introduces nearly 2.4 times the spherical aberration that the CD format 0.45 NA introduces to the system. The spherical aberration of the cover plate and the spherical aberration of the objective, therefore, work in concert for the CD and for the DVD systems to produce similar amounts of system spherical aberration. Although the amount of spherical aberration for the two systems is similar, the distribution of spherical aberration across the aperture of the lens is different for the two systems and this limits the aberration correction to a less than diffraction-limited condition. In addition, the CD and DVD systems operate at different wavelengths and the refractive index of the plastic changes with wavelength in such a way that the distribution of spherical aberration across the lens aperture also changes with wavelength. Optical designers recognize this condition as spherochromatism.

The first embodiment of this invention utilizes the discovery that a single element objective lens can be used for both CD and DVD operation because the amount of spherical

aberration for the two systems is similar and can be controlled to nearly diffraction-limited levels by the correct choice of aspheric surface profiles in the central zone 25 and in the outer zone 26 of the objective.

Fig. 5 shows the first embodiment objective. The 0.45 NA, 780 nm ray fans are shown passing through the central zone 25 of the lens aperture. The 0.60 NA, 650 nm ray fans are shown extending across the full aperture of the lens, which includes the central zone 25 and outer zone 26. Although the diameter of the outer zone appears only slightly larger than the central zone diameter, nearly 0.5 of the energy in the DVD system resides in this outer zone. The ability to independently modify these outer zone surface profiles gives the designer a strong control of the DVD system aberrations that is independent of the CD system aberrations. The two different cover plate thicknesses are shown in this figure. The laser diodes and disk drive are not shown.

The first surface 21 and second surface 22 shown in Fig. 5 can be described in the following mathematical terms:

a first aspheric surface defined as:

$$sag_1 = \frac{\rho_1 r^2}{1 + SQT[1-(1+k_1)\rho_1^2 r^2]} + A_1 r^4 + B_1 r^6 + C_1 r^8 + D_1 r^{10} \ldots$$

and a second surface having an aspheric profile defined as:

$$sag_2 = \frac{\rho_2 r^2}{1 + SQT[1-(1+k_2)\rho_2^2 r^2]} + A_2 r^4 + B_2 r^6 + C_2 r^8 + D_2 r^{10} \ldots$$

Where sag represents sagittal height, and

ρ_1	=	1/radius of first surface vertex
ρ_2	=	1/radius of second surface vertex
k_1	=	conic coefficient of first surface ($-3.5 < k_1 < 0.0$)
k_2	=	conic coefficient of second surface ($-15.0 < k_2 < -5.0$)
A_1 through D_1 and A_2 through D_2	=	general aspheric terms and are non-zero on at least one of said first or second surfaces, and

the vertex curvatures ρ_1 and ρ_2 satisfy $0.667 < \frac{|\rho_1|}{|\rho_2|} < 1.50$

Fig. 6 shows the wavefront errors of the first embodiment objective (shown in Fig. 5) for both the CD and DVD operating conditions. Note that the P-V wavefront error for the DVD case is about the Rayleigh limit of 0.250 wave.

Fig. 7 shows the RMS wavefront error for the system of Fig. 5 through the depth of focus and verifies that the nominal system is at the limit of being diffraction-limited and that there is essentially no margin for fabrication tolerances. The first embodiment is a theoretically viable solution but it requires very tight manufacturing processes to produce economic yields.

The preferred embodiment uses a diffractive surface on one side of the objective. Diffractive surfaces introduce an additional aberration-correction feature that refractive aspheric surfaces cannot provide. Diffractive surfaces change the wavefront differently for different wavelengths. A positive powered diffractive surface bends longer wavelength light more

than shorter wavelength light. This is the opposite behavior of a refractive aspheric surface. This new aberration-correction feature permits a single element objective lens to correct most of the spherochromatism that limits the performance of a simple refractive aspheric lens.

Fig. 8 shows the preferred embodiment single element objective lens 120. The first surface 121 nearest the disk is aspheric and the second surface 122 furthest from the disk has a diffractive surface imposed on a spherical base curve. The diffractive surface provides the same aspheric correction of spherical aberration provided by a refractive aspheric surface but also provides spherochromatism correction. The objective has a slightly different back focal distance for the two wavelengths of interest but this is unimportant because the autofocus mechanism brings the objective to its best focus.

Diffractive surfaces are known in the prior art where they are widely used to correct the chromatic aberration of a singlet operating over a broad spectral band or to correct the spherical aberration of a singlet over a very narrow spectral band. The use of a diffractive surface to correct sperochromatism of a singlet operating at two different wavelengths is not known in the prior art.

A diffractive surface consists of microscopic grooves in the surface of an optical element. The grooves are widest at the center of the optical element and progressively decrease groove width toward the periphery of the element. The groove width is

similar in magnitude to the wavelength of light being used, so the grooves act as a diffraction grating to bend the light. The bending of light is due to diffraction rather than refraction (as produced by Fresnel lenses). Because the groove widths become smaller near the element periphery, the incident wavefront bends more near the edge of the optical element than at the center and the wavefront is therefore focused by diffraction.

Because diffraction is wavelength dependent, the wavefront focusing changes with wavelength to correct chromatic aberration. Because the rate at which the groove widths change can be adjusted to make the surface behave like an aspheric refractive surface, spherical aberration can be corrected.

Fig. 12 shows an exaggerated view of the diffractive surface. The actual groove depth is about 1.0 micrometer. The diffractive surface is described by a polynomial phase function which expresses how many waves of optical path are added or subtracted from each radial zone of the wavefront. The polynomial phase function is

$$\text{Phase} = C_2r^2 + C_4r^4$$

Where C_2 = diffractive power term which controls chromatic aberration correction

and = $0.01<C_2<0.05$

C_4 = aspheric power term which controls spherical aberration correction

and = $0.0005<C_4<0.005$

The first surface 121 shown in Fig. 8 can be described mathematically as follows:

a first aspheric surface defined as:

$$sag_1 = \frac{\rho_1 r^2}{1 + SQT[1-(1+k_1)\rho_1^2 r^2]} + A_1 r^4 + B_1 r^6 + C_1 r^8 + D_1 r^{10}\ldots$$

the second surface 122 has a spherical profile on which is imposed a diffractive surface 122d. The diffractive surface 122d has a polynomial phase function with at least the second and fourth power terms non-zero where

$$\text{Phase} = C_2 r^2 + C_4 r^4$$

Fig. 9 shows the wavefront error for the diffractive objective of Fig. 8. It is significant that the wavefront error vertical scale is ten times more sensitive than the prior plots. The wavefront error is essentially zero and the more sensitive scale is needed to see any wavefront error in this plot.

Fig. 10 shows the depth of focus properties of the diffractive objective of Fig. 8. The performance of the 0.45 NA, 780 nm system is better than the prior art. This permits a slightly greater fabrication tolerance margin compared to prior art objective lenses. The 0.60 NA, 650 nm nominal system depth of focus is about ± 1.0 micrometer. After fabrication tolerances are considered, the depth of focus will be on the order of ± 0.7 micrometer. This is equivalent to the depth of focus that can be achieved by a 0.60 NA, 650 nm objective that only operates with a DVD format reader.

Fig. 11 shows an important feature of diffractive surfaces. The percentage of light that is focused by a diffractive surface is wavelength dependent and several different images can be produced in different diffraction orders. The proper choice of the diffractive surface depth will cause essentially all of the energy in one wavelength to be in the image of the preferred first diffraction order. Because the optimum depth is wavelength dependent and the laser diodes operate at 780 nm and 650 nm, not all of the energy in these two wavelengths can be directed into their respective first order images. The depth of the diffractive surface of this invention is, therefore, chosen midway between these two wavelengths at a wavelength value of 715 nm.

Fig. 11 shows that 0.97 of the energy is directed to the respective first order images when this condition is met. The remaining 0.03 of the energy is primarily directed into the zero diffraction order and is distributed over a large area of the optical disk and produces a negligible background signal.

Modifications of design may be made without departing from the invention. For example, the diffractive surface may be carried by the lens surface 21 closest to the disk. Various types of collimators and beam-splitters may be used as well as laser diodes of various wavelengths. Various materials may be used for the objective lens, including glass and PMMA.

8998.100

WHAT IS CLAIMED IS:

1. An optical disk reader or optical read/write system capable of operating in either a compact disk (CD) or digital versatile disk (DVD) format, comprising:

disk support and drive means capable of supporting and driving either a compact disk having a cover plate of thickness Y or a digital versatile disk having a cover plate of thickness X,

a first laser diode operating with an output beam having a first wavelength,

a second laser diode operating with an output beam having a second wavelength different from said first wavelength,

optical means for either directing the output beam of said first laser diode at a said compact disk when carried by said disk support and drive means or directing the output beam of said second laser diode at a said digital versatile disk when carried by said disk support and drive means, and

a single element objective lens optically positioned between said disk support and drive means on one end and said first and second laser diodes on another end,

said single element objective lens having a central aperture zone and an outer aperture zone, said central aperture zone being profiled to operate at a first numerical aperture (NA) and said output beam of said first laser diode being optically confined to said central aperture zone, and

said outer aperture zone together with said central aperture zone being profiled to operate at a second numerical aperture (NA) and wherein said output beam of said second laser diode has ray fans extending across the full aperture of said lens.

2. The apparatus of claim 1 wherein said first surface is located closer to said disk support and drive means than said second surface and further comprising diffractive means carried by said second surface, said diffractive means providing sufficient aspheric surface power for spherical aberration correction and providing correction for spherochromatism.

3. The apparatus of claim 1 wherein said first surface is located closer to said disk support and drive means than said second surface and further comprising diffractive means carried by said first surface, said diffractive means providing sufficient aspheric surface power for spherical aberration correction and providing correction for spherochromatism.

4. The apparatus of claim 2 wherein said diffractive means provides sufficient correction for spherical aberration and for spherochromatism that said single element objective lens achieves diffraction-limited image quality for both CD and DVD formats.

5. The apparatus of claim 1 wherein said single element objective lens is molded cyclic olefin copolymer or PMMA.

6. An optical disk reader or optical read/write system capable of operating in either a compact disk (CD) or digital versatile disk (DVD) format, comprising:

disk support and drive means capable of supporting and driving either a compact disk having a cover plate of thickness 2X or a digital versatile disk having a cover plate of thickness X,

a first laser diode operating with an output beam wavelength of approximately 780 nm,

a second laser diode operating with an output beam wavelength of approximately 650 nm,

optical means for either directing the output beam of said first laser diode at a said compact disk when carried by said disk support and drive means or directing the output beam of said second laser diode at a said digital versatile disk when carried by said disk support and drive means, and

a single element objective lens optically positioned between said disk support and drive means on one end and said first and second laser diodes on another end, said single element objective lens having first and second surfaces, said first surface having an aspheric profile,

said single element objective lens having a central aperture zone and an outer aperture zone, said central aperture zone being profiled to operate at approximately a 0.45 numerical aperture (NA) and said output beam of said first laser diode being optically confined to said central aperture zone, and

said outer aperture zone together with said central aperture zone being profiled to operate at approximately a 0.60 numerical aperture (NA) and wherein said output beam of said second laser diode has ray fans extending across the full aperture of said lens.

7. The apparatus of claim 6 wherein said first surface is located closer to said disk support and drive means than said second surface and further comprising diffractive means carried by said second surface, said diffractive means providing sufficient aspheric surface power for spherical aberration correction and providing correction for spherochromatism.

8. The apparatus of claim 7 wherein said diffractive means provides sufficient correction for spherical aberration and for spherochromatism that said single element objective lens achieves diffraction-limited image quality for both CD and DVD formats.

9. The apparatus of claim 6 wherein said single element objective lens is molded cyclic olefin copolymer or PMMA.

10. The apparatus of claim 6 wherein said diffractive means has a predetermined depth to optimize diffraction efficiency for both laser diode wavelengths.

11. A single element objective lens for use in an optical disk reader or read/write system for either a CD format operating with an approximately 780 nm laser diode or a DVD format operating with an approximately 650 nm laser diode, wherein said single element lens has first and second surfaces and comprises:

a first aspheric surface defined as:

$$sag_1 = \frac{\rho_1 r^2}{1 + SQT[1-(1+k_1)\rho_1^2 r^2]} + A_1 r^4 + B_1 r^6 + C_1 r^8 + D_1 r^{10} \ldots$$

and a second surface having an aspheric profile defined as:

$$sag_2 = \frac{\rho_2 r^2}{1 + SQT[1-(1+k_2)\rho_2^2 r^2]} + A_2 r^4 + B_2 r^6 + C_2 r^8 + D_2 r^{10} \ldots$$

Where *sag* represents sagittal height and

ρ_1	=	1/radius of first surface vertex
ρ_2	=	1/radius of second surface vertex
k_1	=	conic coefficient of first surface ($-3.5 < k_1 < 0.0$)
k_2	=	conic coefficient of second surface ($-15.0 < k_2 < -5.0$)
A_1 through D_1 and A_2 through D_2	=	general aspheric terms and are non-zero on at least one of said first or second surfaces, and

the vertex curvatures ρ_1 and ρ_2 satisfy $0.667 < \frac{|\rho_1|}{|\rho_2|} < 1.50$

12. A single element objective lens for use in an optical disk reader or read/write system for either a CD format operating with an approximately 780 nm laser diode or a DVD format operating with an approximately 650 nm laser diode, wherein said lens has first and second surfaces and comprises:

a first aspheric surface defined as:

$$sag_1 = \frac{\rho_1 r^2}{1 + SQT[1-(1+k_1)\rho_1^2 r^2]} + A_1 r^4 + B_1 r^6 + C_1 r^8 + D_1 r^{10} \ldots$$

Where *sag* represents sagittal height and

ρ_1 = 1/radius of first surface vertex

k_1 = conic coefficient of first surface ($-3.5 < k_1 < 0.0$)

A_1 through D_1 = general aspheric terms and are non-zero on at least one of said first or second surfaces, and

the vertex curvatures ρ_1 and ρ_2 satisfy $0.667 < \frac{|\rho_1|}{|\rho_2|} < 1.50$

a second spherical surface including a diffractive surface with a polynomial phase function having at least the second and fourth power terms non-zero where

$$\text{Phase} = C_2 r^2 + C_4 r^4$$

and = $0.01 < C_2 < 0.05$

and = $0.0005 < C_4 < 0.005$

Abstract of the Disclosure

An optical disk reader or read/write system for CD or DVD formats. First and second laser diodes operating at different wavelengths have their output beams collimated and directed at a single element objective lens, and are then reflected off the disk back through the lens to a photodetector. The single element objective lens has a central aperture zone and an outer aperture zone, the central zone being profiled to operate at a first numerical aperture at approximately 0.45 and the output beam of the first laser diode is confined to the central aperture zone. The outer aperture zone together with the central aperture zone are profiled to operate at a second numerical aperture, for example 0.60 wherein the output beam of the second laser diode has ray fans extending across the full aperture of the single element objective lens. A diffractive is formed on one surface of the single element objective lens and provides sufficient aspheric surface power for spherical aberration correction as well as correction for spherochromatism. The diffractive also provides sufficient correction for spherical aberration and spherochromatism that the single element objective lens achieves diffraction-limited image quality for both CD and DVD formats.

8998.102

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) & 1.27(b))--INDEPENDENT INVENTOR	**Docket Number (Optional)** 8998

Applicant or Patentee: BARRY G. BROOME ET AL

Application or Patent No.:

Filed or Issued:

Title: SINGLE OBJECTIVE LENS FOR USE WITH CD OR DVD OPTICAL DISKS

As a below named inventor, I hereby declare that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- [X] the specification filed herewith with title as listed above.
- [ ] the application identified above.
- [ ] the patent identified above.

I have not assigned, granted, conveyed or licensed and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- [ ] No such person, concern, or organization exists.
- [X] Each such person, concern or organization is listed below.

Universal Lightspeed, Inc.
1170 Terra Bella Avenue
Mountain View, California 94043

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Barry G. Broome	Jenkin A. Richard	
NAME OF INVENTOR	NAME OF INVENTOR	NAME OF INVENTOR
Barry G. Broome	Jenkin Richard	
Signature of inventor	Signature of inventor	Signature of inventor
4/15/98	5/5/98	
Date	Date	Date

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) & 1.27(c))--SMALL BUSINESS CONCERN	Docket Number (Optional) 8998

Applicant or Patentee: BARRY G. BROOME ET AL

Application or Patent No.: ______

Filed or Issued: ______

Title: SINGLE OBJECTIVE LENS FOR USE WITH CD OR DVD OPTICAL DISKS

I hereby declare that I am

☐ the owner of the small business concern identified below:

☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN Universal Lightspeed, Inc.

ADDRESS OF SMALL BUSINESS CONCERN 1170 Terra Bella Avenue Mountain View, CA 94043

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.12, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

☒ the specification filed herewith with title as listed above.

☐ the application identified above.

☐ the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights in the invention must file separate verified statements averring to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern or organization having any rights in the invention is listed below:

☐ no such person, concern, or organization exists.

☐ each such person, concern or organization is listed below.

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

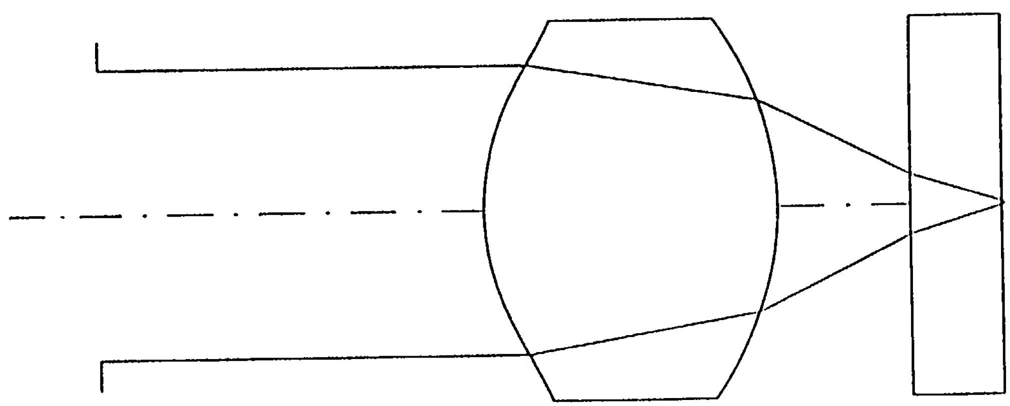
I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING Jenkin A. Richard

TITLE OF PERSON IF OTHER THAN OWNER PRESIDENT

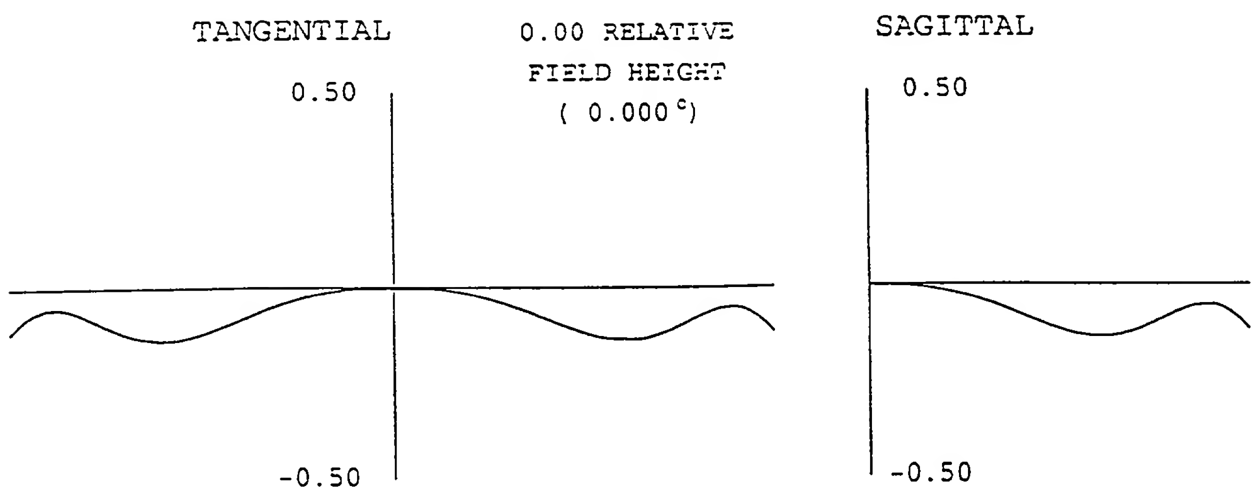
ADDRESS OF PERSON SIGNING 1170 Terra Bella Avenue Mountain View, CA 94043

SIGNATURE Jenki Richard DATE 5/5/98



PRIOR ART EXAMPLE

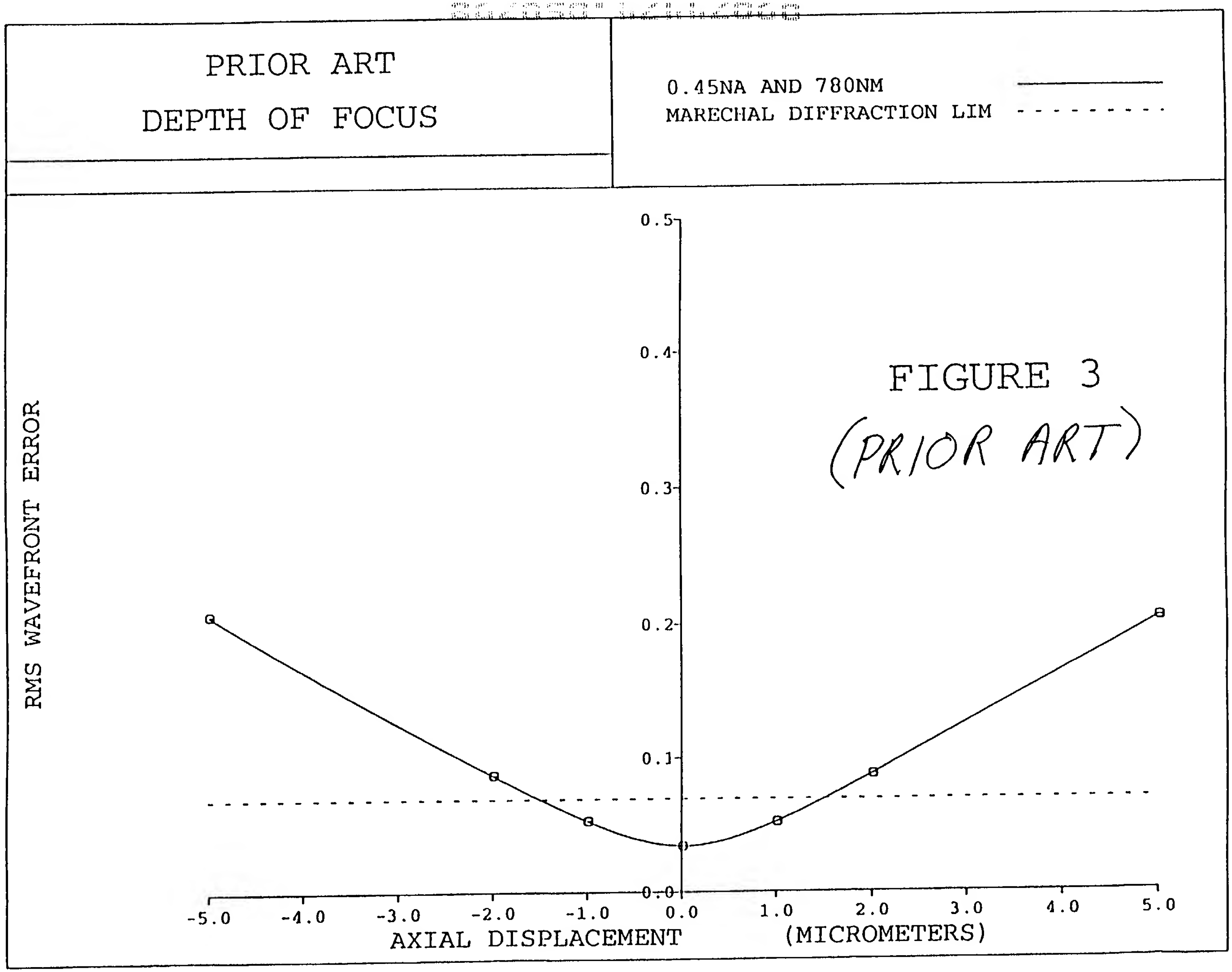
FIGURE 1



0.140 WAVE P-V

0.035 WAVE RMS

FIGURE 2 (PRIOR ART)


PRIOR ART
DEPTH OF FOCUS
0.45NA AND 780NM
MARECHAL DIFFRACTION LIM
RMS WAVEFRONT ERROR
0.5
0.4
0.3
0.2
0.1
0.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
AXIAL DISPLACEMENT (MICROMETERS)
FIGURE 3
(PRIOR ART)

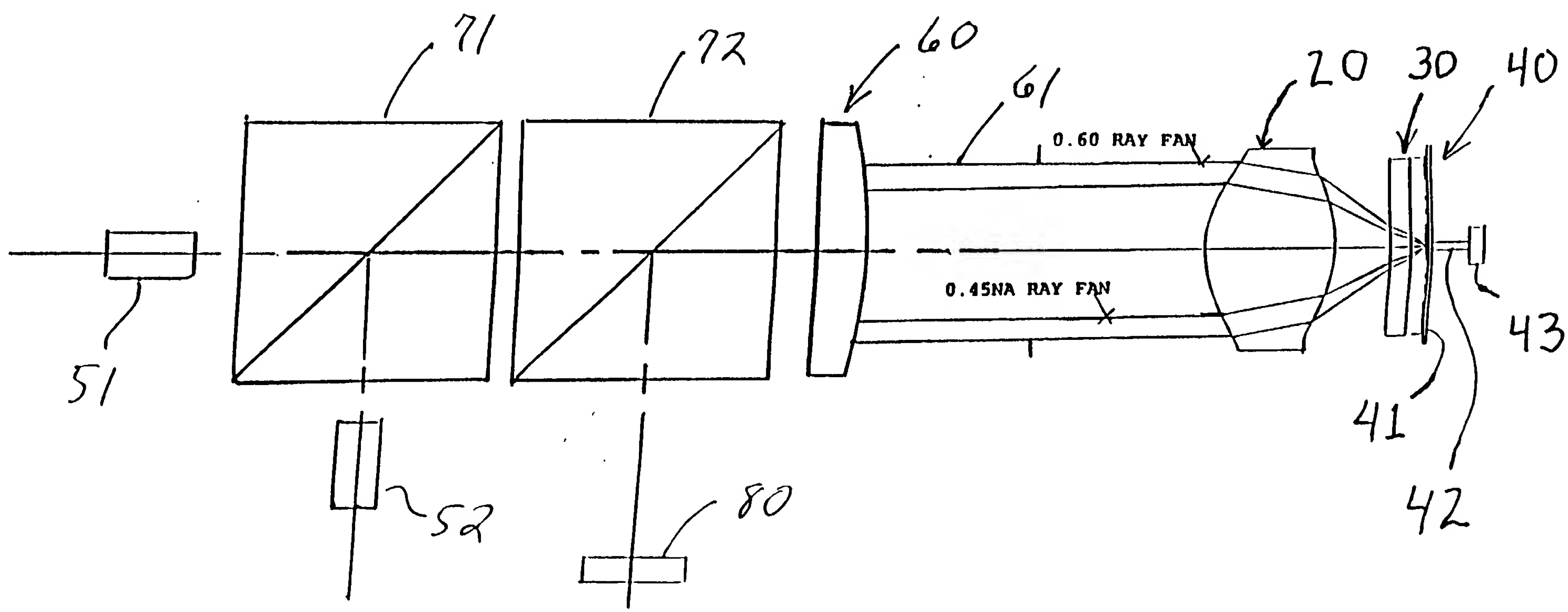


FIG 4

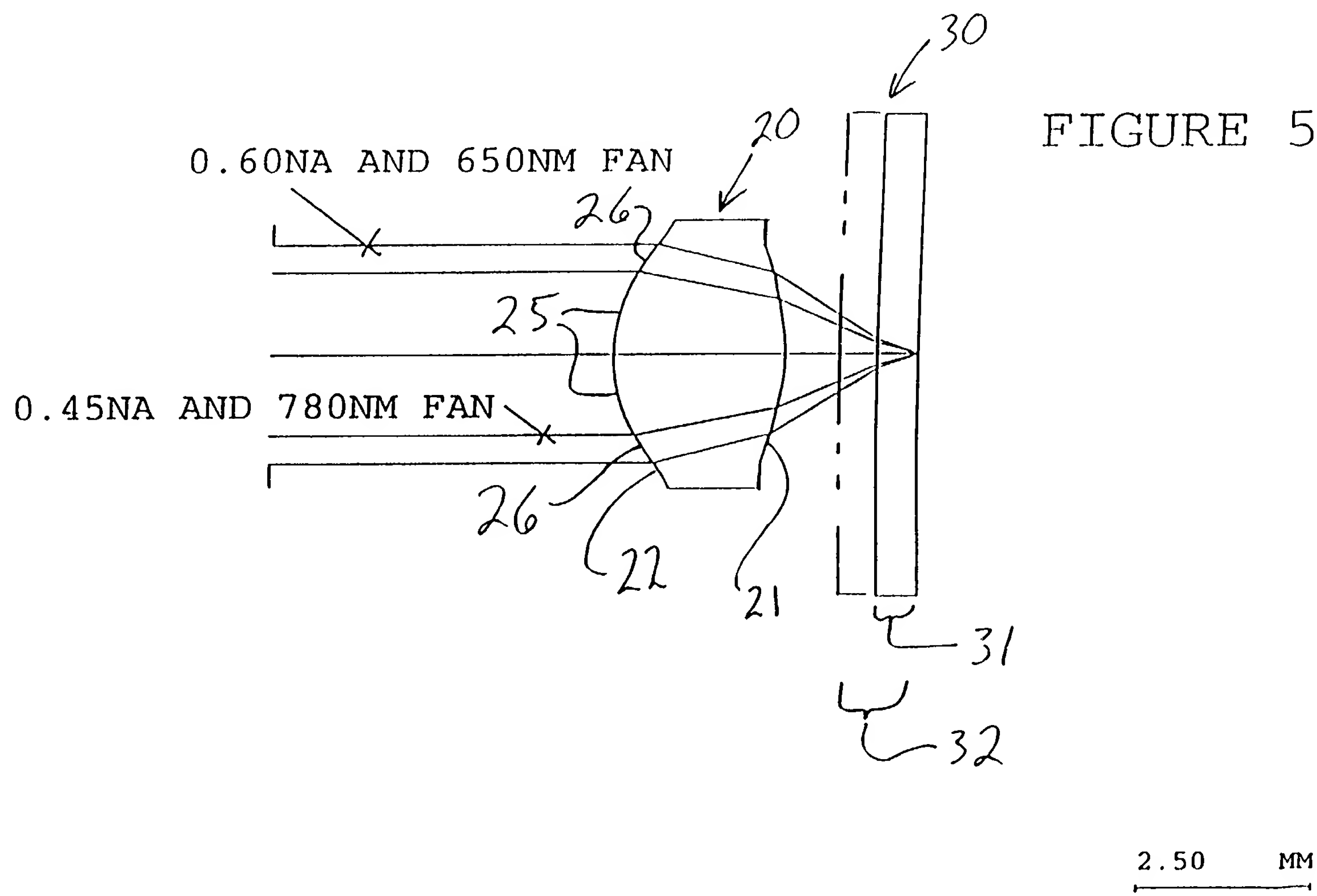
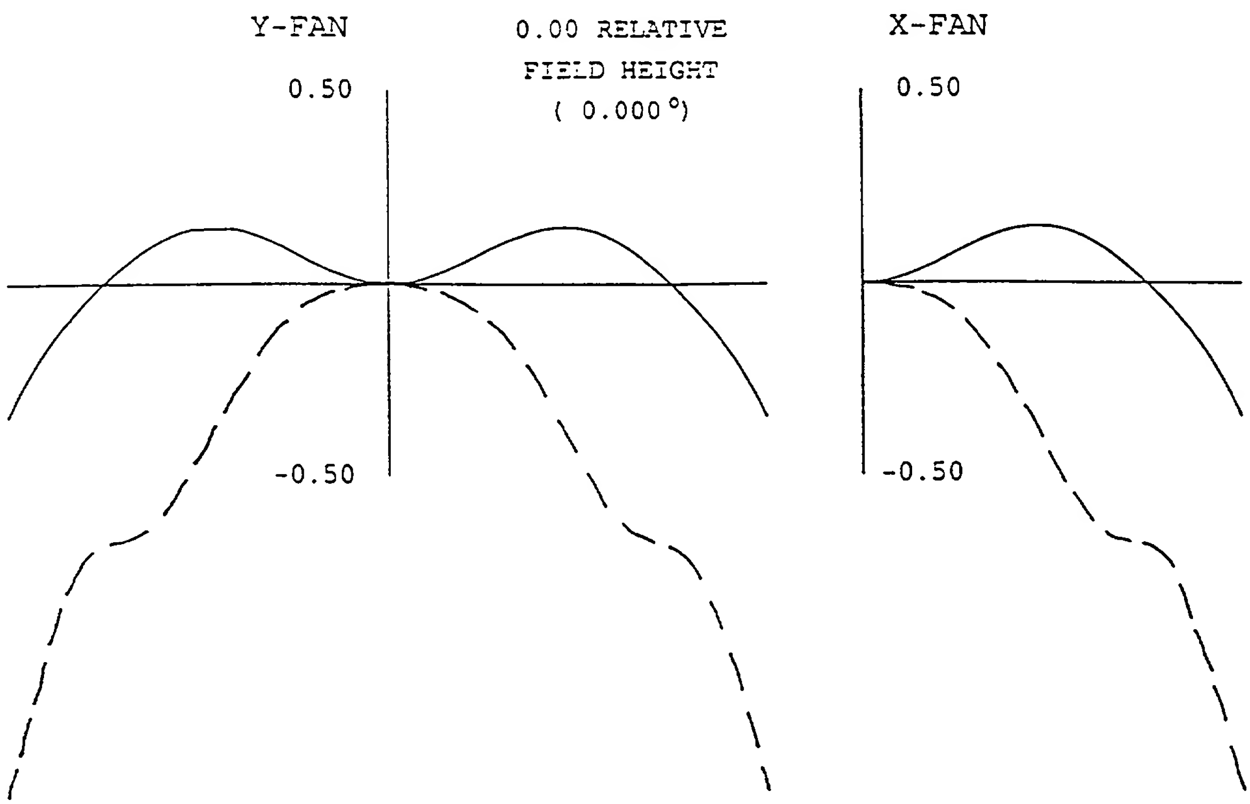


FIGURE 5

CD/DVD FOCUS LENS

Position: 2
Scale: 10.00

FIGURE 6



CD/DVD FOCUS LENS

OPTICAL PATH DIFFERENCE (WAVES)

POSITION 1

650.0 NM
780.0 NM

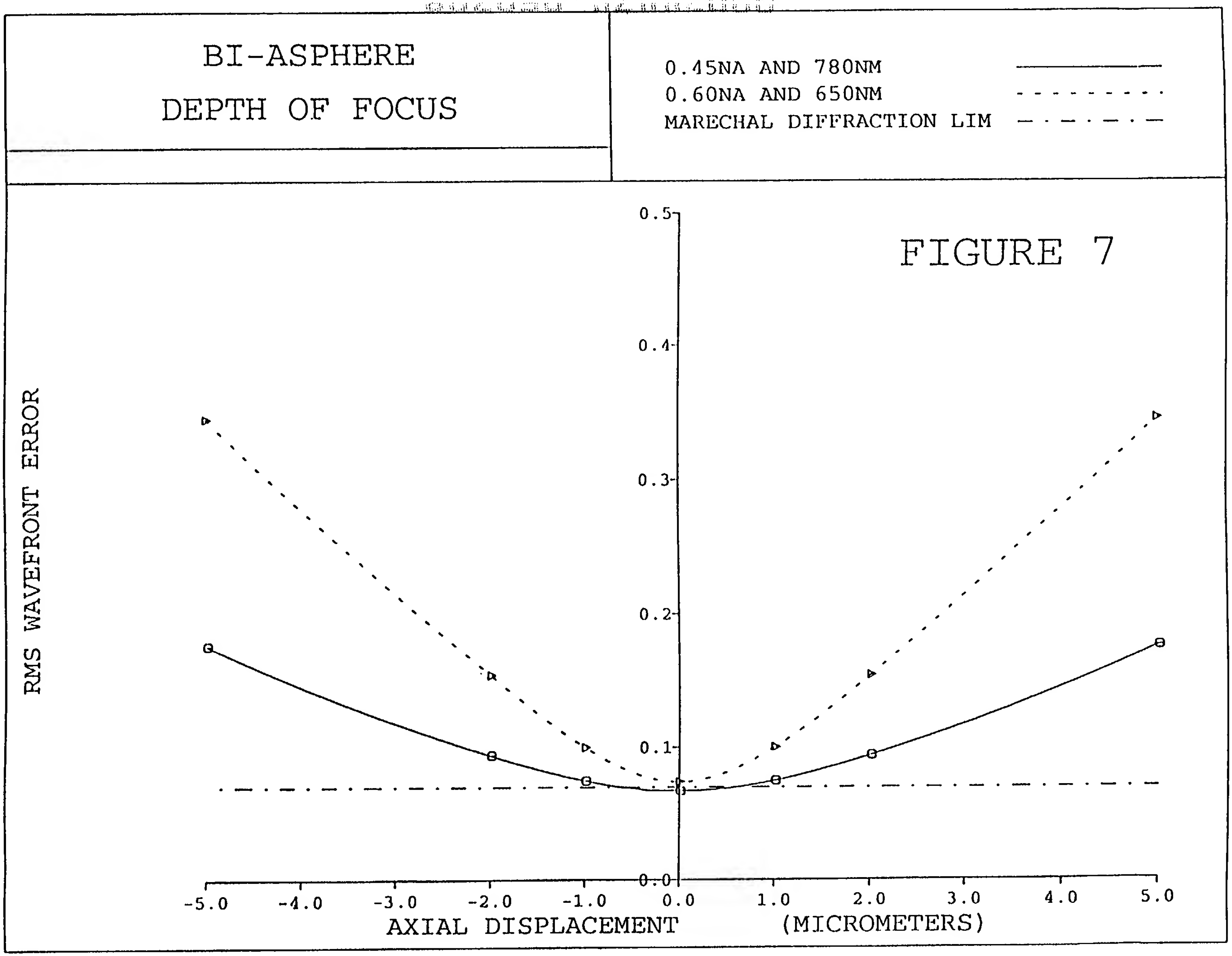
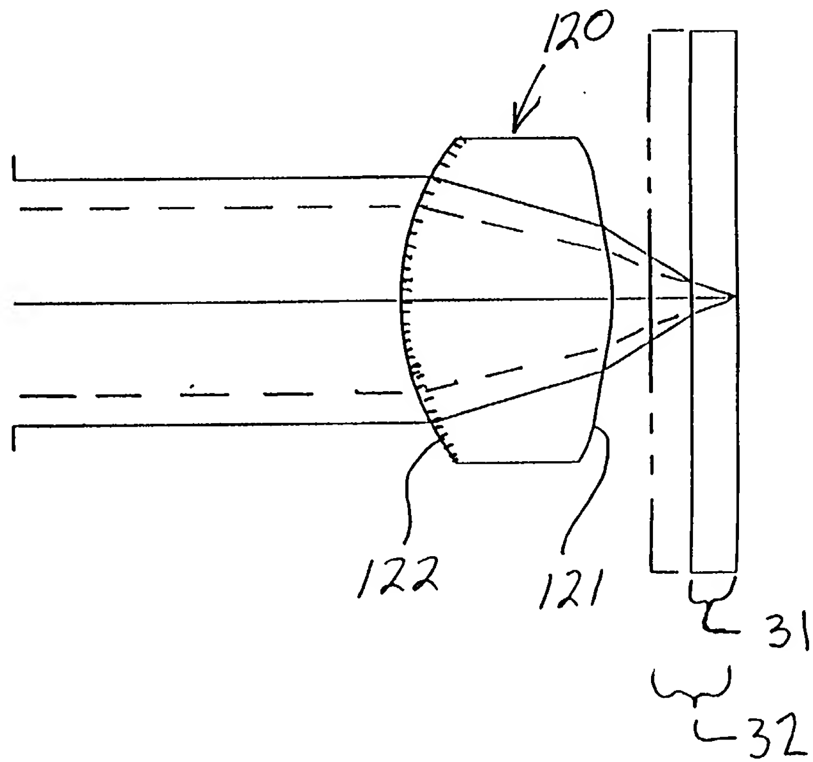

BI-ASPHERE
DEPTH OF FOCUS
0.45NA AND 780NM
0.60NA AND 650NM
MARECHAL DIFFRACTION LIM
RMS WAVEFRONT ERROR
0.5
0.4
0.3
0.2
0.1
0.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
AXIAL DISPLACEMENT (MICROMETERS)

FIGURE 7

FIGURE 8

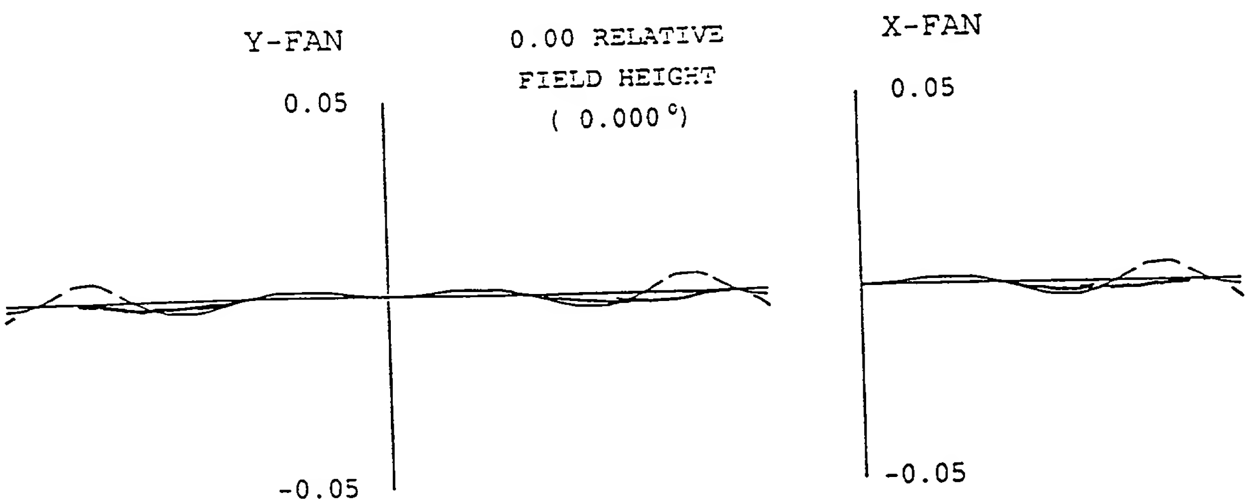


2.50 MM

CD/DVD FOCUS LENS

Position: 2
Scale: 10.00

FIGURE 9



CD/DVD FOCUS LENS

OPTICAL PATH DIFFERENCE (WAVES)

POSITION 2

- - - - - - - 650.0 NM
——————— 780.0 NM

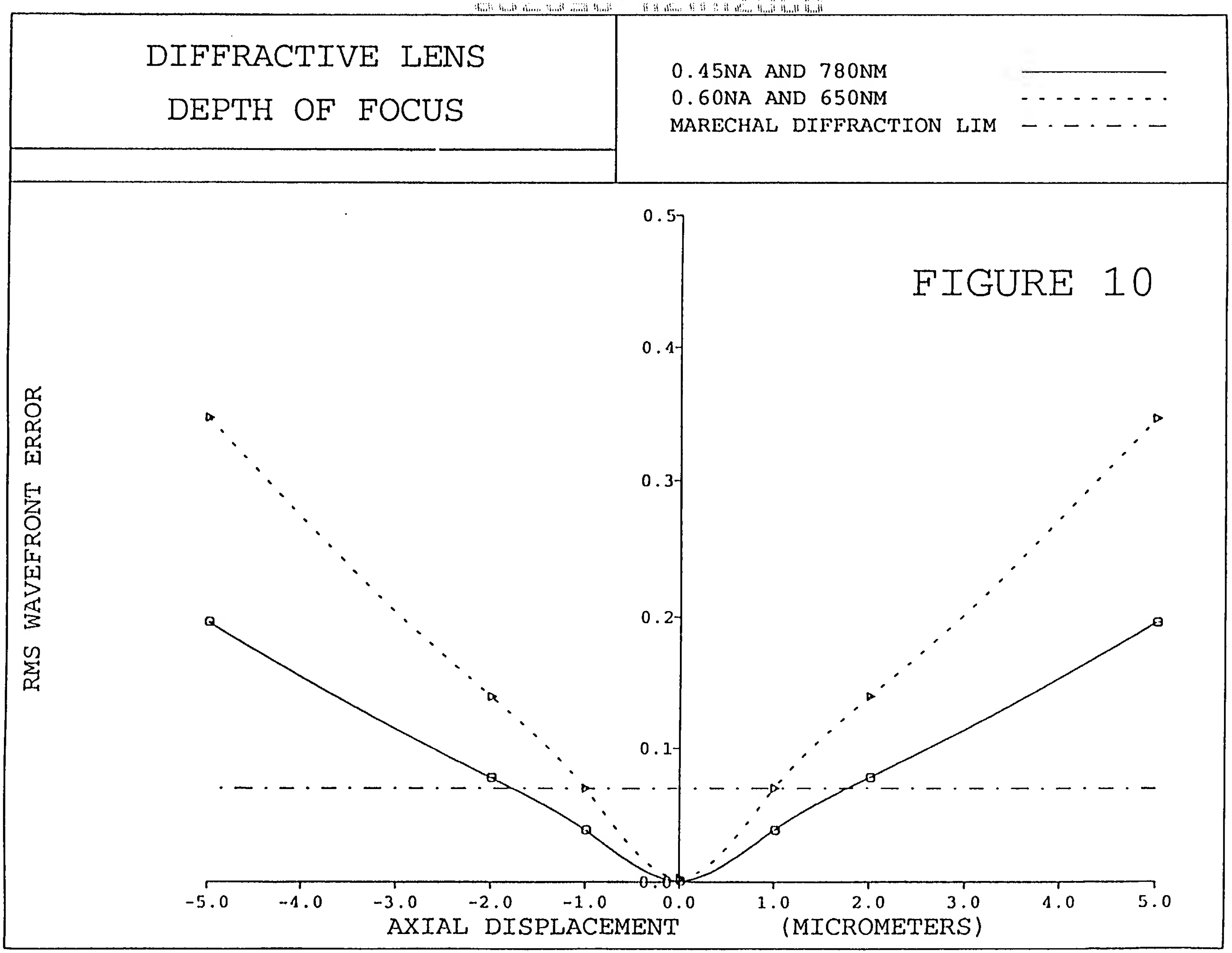

DIFFRACTIVE LENS
DEPTH OF FOCUS
0.45NA AND 780NM
0.60NA AND 650NM
MARECHAL DIFFRACTION LIM
RMS WAVEFRONT ERROR
0.5
0.4
0.3
0.2
0.1
0.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
AXIAL DISPLACEMENT (MICROMETERS)

FIGURE 10

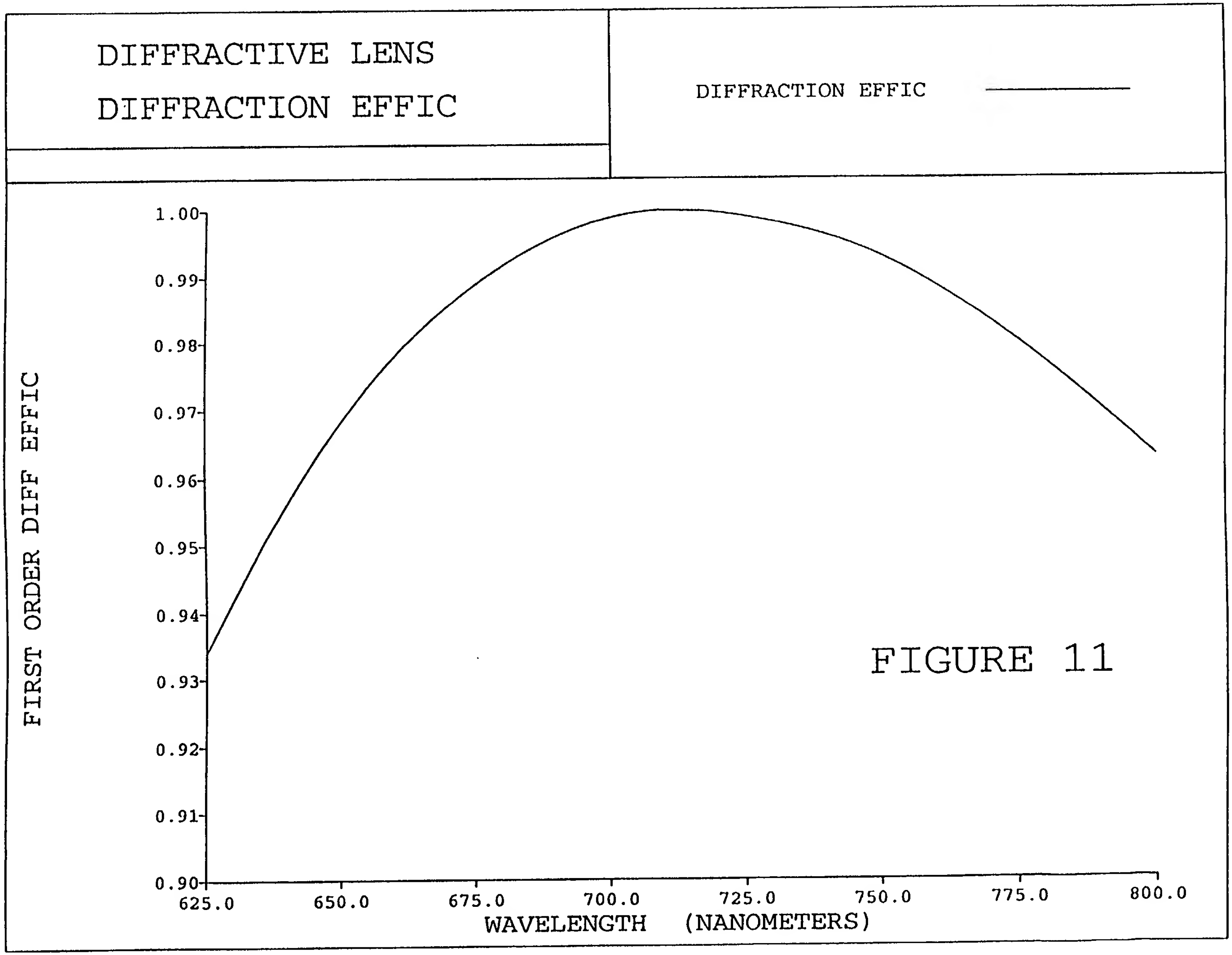
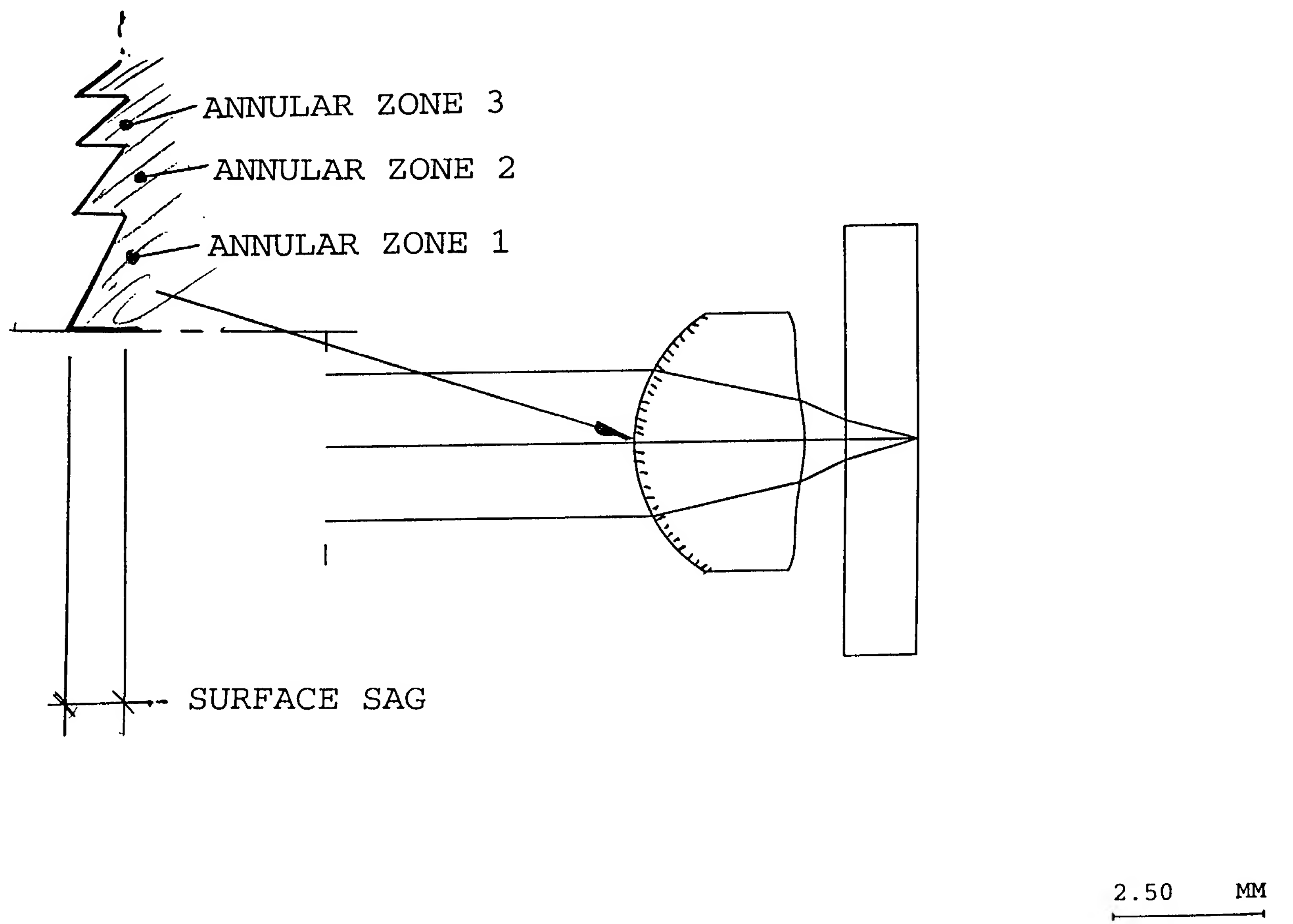

DIFFRACTIVE LENS
DIFFRACTION EFFIC
DIFFRACTION EFFIC
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.90
625.0
650.0
675.0
700.0
725.0
750.0
775.0
800.0
WAVELENGTH (NANOMETERS)
FIRST ORDER DIFF EFFIC

FIGURE 11



CD/DVD FOCUS LENS

Position: 1
Scale: 10.00

FIGURE 12

Please type a plus sign (+) inside this box → ☐

PTO/SB/01 (3-97)
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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION

☒ Declaration Submitted with Initial Filing OR ☐ Declaration Submitted after Initial Filing

Attorney Docket Number	8998
First Named Inventor	BARRY G. BROOME ET AL
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled :

SINGLE OBJECTIVE LENS FOR USE
WITH CD OR DVD OPTICAL DISKS

(Title of the Invention)

the specification of which

☒ is attached hereto

OR

☐ was filed on (MM/DD/YYYY) ____ as United States Application Number or PCT International Application Number ____ and was amended on (MM/DD/YYYY) ____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119 (a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or §365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
		☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

PTO/SB/01 (3-97)

Please type a plus sign (+) inside this box → ☐

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Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under Title 35, United States Code §120 of any United States application(s), or §365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: ☐ Customer Number ______ → Place Customer Number Bar Code Label here
OR
☒ Registered practitioner(s) name/registration number listed below

Name	Registration Number	Name	Registration Number
Bruce H. Johnsonbaugh	24,982		

☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

Direct all correspondence to: ☐ Customer Number or Bar Code Label ______ OR ☒ Correspondence address below

Name	Bruce H. Johnsonbaugh				
Address	Eckhoff, Hoppe, Slick, Mitchell & Anderson				
Address	Four Embarcadero Center, Suite 760				
City	San Francisco	State	CA	ZIP	94111
Country	U.S.A.	Telephone	415-391-7160	Fax	415-391-7164

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
Barry G.	Broome

Inventor's Signature	Barry G. Broome					Date	4/15/98
Residence: City	Carlsbad	State	CA	Country	U.S.A.	Citizenship	USA
Post Office Address	4812 Courageous Lane						
Post Office Address							
City	Carlsbad	State	CA	ZIP	92008	Country	U.S.A.

☒ Additional inventors are being named on the ____ supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

Please type a plus sign (+) inside this box → ☐

DECLARATION

ADDITIONAL INVENTOR(S) Supplemental Sheet

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name	Jenkin	Middle Initial	A	Family Name	Richard	Suffix e.g. Jr.	
Inventor's Signature	Jenkin Richard			Date	5/5/98		
Residence: City	Mountain View	State	CA	Country	U.S.A.	Citizenship	USA
Post Office Address	1375 Montecito Avenue #13						
Post Office Address							
City	Mountain View	State	CA	Zip	94043	Country	U.S.A.

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name		Middle Initial		Family Name		Suffix e.g. Jr.	
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		Zip		Country	

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name		Middle Initial		Family Name		Suffix e.g. Jr.	
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		Zip		Country	

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name		Middle Initial		Family Name		Suffix e.g. Jr.	
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		Zip		Country	

☐ Additional inventors are being named on supplemental sheet(s) attached hereto